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EXPERIMENTS WITH THE BURROUGHS B 3500 COMPUTER SYSTEM USING A SYNTHETIC WORKLOAD

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An application of synthetic workloads in the evaluation of the performance of batch processing, multiprogrammed, real-memory computer systems is described. Results of controlled experiments with a Burroughs B 3500 computer system in a dedicated environment using a testworkload are presented. The test workload is constructed by matching the joint probability distribution of the selected real workload characteristics. They are the core size of the program, the number of files, I/0 activity to disk and the CPU time. These characteristics are determined from the system accounting package, LOGGER. The

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accounting data, collected by LOGGER during the controlled experiments with the synthetic workload, are used to determine the utilization of the processor and the I/0 channel. These utilization values compare favorably with those measured by a DYNAPROBE 7900 hardware monitor.

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SECTION I

INTRODUCTION

The performance of computer systems is usually evaluated for the purposes of determining its present value, methods of improving it and predicting the effects of changes in either the workload or the system. One method of studying these factors is to conduct experiments with an existing system using a test workload. This report describes the results of and experiences from an experimental investigation with a Burroughs B 3500 computer system at ESD, Hanscom Air Force Base.

In order to conduct these experiments there is a need for a stable, reproducible and flexible test workload that imitates the real workload with reasonable fidelity but in an abbreviated form. It is necessary that the test workload be stable and reproducible so that the experimental results are interpreted correctly; the test workload be flexible so that the characteristics of the test workload may be varied; and the test workload be a representative model of the real workload so that valid conclusions may be drawn from its use. All these requirements can be fulfilled by using synthetic programs in the test workload.

The test workload used in the experiments is constructed by matching the joint probability density for the selected workload characteristics of the real workload with those of the test workload. The selected characteristics are the processor time, the I/O activities to disk, the number of files and the amount of core used by each job. These characteristics are determined from the LOGGER accounting data maintained by the Master Control Program (MCP-V) of the Burroughs B 3500 system. The details of the various types of records collected by LOGGER are studied and special conversion

packages are implemented to create a job summary record for every job processed. These summary records are used to determine the test workload characteristics.

In these experiments the utilization of the processor and the channel is measured using a DYNAPROBE 7900* hardware monitor. These utilization values are also calculated using the LOGGER data. The two sets of values compare favorably. This is a significant finding of this investigation. The utilization values of the system resources are essential in the evaluation of the computer performance. This study indicates that the accounting data (LOGGER) provides a ready and economical source for determining the resource utilization. A system manager can conveniently assess the system performance by periodic processing of the accounting data to determine the resource utilization.

The test workload is only a model of the real workload and is constructed by striking a compromise between the needs of representativeness and physical constraints such as the processor time used. Such a compromise necessarily renders the synthetic workload not completely representative of all the features of the real workload. This is indeed the case in our study where the test workload is constructed using only four of the many characteristics recorded by the accounting data. The tape I/O activities are not represented because it was decided not to consider the human factors involved in the tape handling. Special measurements have to be made to include the tape I/O activities in the test workload. These measurements relate to the method of handling tapes.

The construction of the test workload is outlined in Section II. Section III describes the experiments. The report is summarized in Section IV and the method of calculating the resource utilization is described in the Appendix.

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*Comress, Incorporated.

SECTION II

CONSTRUCTION OF TEST WORKLOAD

GENERAL DESCRIPTION

A workload is defined as the collection of all the individual jobs that are processed by a computer system during a specified period of time. The computer system can be considered as a collection of resources upon which the workload places certain demands. The magnitude of these demands can be viewed as the characteristic variables of the real workload. A job, such as a compilation, matrix inversion, or sort-merge can be described by a set of these variables whose magnitudes will vary from one type of job to another, and from one computer system to another.

In this method of characterizing the workload it is assumed that since the system does not recognize the type of job, two jobs reflecting the same value for the characteristic variables are treated identically by the operating system. This assumption is reasonable since the operating system classifies jobs on the basis of the demands they place on the system resources.

Many computer installations maintain a system accounting package that, for charging purposes, gathers information about the use of various system resources. This information provides a ready source of data from which many of the workload characteristics can be derived. To determine the characteristics not available from the accounting data, hardware and software monitors must be used.

In many installations a significant part of the I/O activities may be directed to tape. This was the case in this study where the workload of the B 3500 (ESD, Hanscom Air Force Base) was studied. In such cases the accounting data seldom record the details of the I/O activities to tape. Examples of these details are: number of tape mounts

and dismounts, time per mount, number of jobs requesting the same tape drive, and forced idle time for a job because of conflicts in tape drive availability. These details are significant and contribute to the overall performance of the computer system. Although these details are system dependent they can best be described as human factors that influence the throughput of the workload. Mounting and dismounting of tapes are not only influenced by the number of tapes and the location of the tape library but also by the number of operators available.

The method of characterizing the workload described in this report does not consider the human factors. This study used the total number of I/O activities to tape or to disk as a measure of the I/O load. This quantity, admittedly, neglects the time for mount and dismount and this is a limitation in this method of characterization.

The tape I/O can be accounted for by creating tape files in the synthetic program. Initial calibration experiments must be conducted to relate the tape block counts (the number of blocks read or written to tape) with the corresponding synthetic program parameters. In the case of tape files, not all the block counts (recorded by the accounting package) lead to data transfer; some of them result in tape positioning, label checking and tape rewinding. The fraction of the total block count resulting in data transfer can be determined in the preliminary calibration experiments. The tape handling in the real workload should then be studied to estimate the time taken for responding to the mount request and the number of tape files processed by individual jobs. Based on these studies it is possible to execute the synthetic program creating tape files and introduce known amounts of delay to simulate tape handling.

PREPROCESSING OF SYSTEM LOG FILE DATA

LOGGER Data

The LOGGER provided the source of performance data for this report. LOGGER is the accounting package provided as a part of the MCP operating system for the B 3500. LOGGER records the following event-oriented statistics. They are usually referred to as the Type X records where X is any one of the following.

Type 0	File Close Record
Type 1	File Open Record
Type 2	End of Job Record
Type 3	Long Schedule Record
Type 4	Short Schedule Record
Type 5	Comment Record
Type 6	Beginning of Job Record
Type 7	Idle Time Record
Type 8	Halt/load Record
Type 9	Filler Record

Data Structure

The accounting package collects and records data in the event-oriented format as and when the events take place. Typically they are: job A begins; job A opens file x; job B begins; job A closes file x; etc. They are also referred to as the raw data. These data are uniquely identified by the job-log number (or the job ID) and using this field as the key the raw data are summarized into job-oriented format, also referred to as the summary data. The job-oriented data, essentially, are the magnitudes of the demands placed on the various system resources by the individual jobs. It should be noted that one job-oriented record is obtained by summarizing several event-oriented records.

The performance variables of interest for this workload characterization were taken from four of the LOGGER record types: Type 0, File Close Record; Type 1, File Open Record; Type 2, End of Job Record; and Type 6, Beginning of Job Record. The record layouts for each of these types are shown in Figures 1 and 2.[1]

The standard internal character set for the B 2500/B 3500 is the 8-bit Extended Binary Coded Decimal Interchange Code (EBCDIC). Internal storage for the accounting data is organized into 4-bit digits and is processed under two formats: unsigned 4-bit numeric and 8-bit alphanumeric. Most of the data uses the unsigned 4-bit numeric format which is the Burroughs structure for high density storage of data.[2] The voluminous quantity of event-oriented records on system activity must be summarized into usable job-oriented summary records. An existing program written in PL/I for the IBM 370/155 (MITRE, Bedford) was modified and used to create job summary records. It was necessary, therefore, to convert the Burrough's LOGGER data into IBM compatible data types. There is no conversion necessary for the 8-bit alphanumeric data but the unsigned 4-bit numeric must be changed by adding a sign and aligning digits on 8-bit (character) boundaries.

ACCESSIBILITY

The event-oriented data collected by the LOGGER is readily accessible. The data set receiving this raw data is normally a disk file. Log procedures of the B 3500 accounting system store information into one of three disk data sets called System Log Files. The raw data of interest in this analysis is in the system run (current) log file and is named RLOG. The disk files are periodically emptied onto tape volumes for storage. The RLOG data, consequently, is available from either the active disk file or the stored tape file.

CLOSE

Position	Contents
0	Type Code
1-4	Reserved
5-8	Log ID Number
9-14	Date (MMDDYY)
15-22	Time (msecs)
23	Subtype
24-35	File ID
36-47	Multi-File ID
48-49	File Number
50-51	Primary I/O Channel
52	Unit Number
53-54	Hardware Type Used
55	Supplementary Hardware Code
56-58	Reel Number
59-63	Physical Tape Number
64-65	Close Type Code
66-73	Logical Record Count
74-81	Physical Record Count
82-84	Exception Count
85-86	Number of Disk Areas Used
87-94	Disk End-of-File Pointer
95	Memory for Disk File Headers
96-99	Reserved

OPEN

Position	Contents
0	Type Code
1-4	Reserved
5-8	Log ID Number
9-14	Date (MMDDYY)
15-22	Time (msecs)
23	Subtype
24-35	File ID
36-47	Multi-File ID
48-49	File Number
50-51	Primary I/O Channel
52	Unit Number
53-54	Hardware Type Requested
55	Supplementary Hardware Code
56-58	Reel Number
59-63	Creation Date
64-65	Cycle Number
66-70	Maximum Record Length
71-73	Records per Block
74-79	Maximum Block Size
80	Buffer Access Technique
81	File Label Convention
82	Number of Alternate Areas
83	OPEN Type Code
84	Recording Mode
85	Blocking Technique
86	Special Forms Indicator
87-89	Save Factor
90-96	Disk Segments per Area
97	Disk Access Technique
98	Disk File Header Block Count
99	Reserved

Figure 1. File Close and Open Records

END

Position	Contents
0	Type Code
1-4	Reserved
5-8	Log ID Number
9-14	Data (MMDDYY)
15-22	Time (msecs)
23	Subtype
24-35	Program ID
36-47	Multi-program ID
48-49	Job Number
50-51	Primary I/O Channel
52	Unit Number
53-54	Hardware Type
55	Supplementary Hardware Type
56-61	Overlay Count
62-63	Finish Code
64-73	Reserved
74-81	Direct Processor
82-89	Prorated Processor Time
90-97	Accumulated Program I/O Wait Time
98-99	Reserved

BEGIN

Position	Contents
0	Type Code
1-4	Reserved
5-8	Log ID Number
9-14	Date (MMDDYY)
15-22	Time (msecs)
23	Subtype
24-35	Program ID
36-47	Multi-program ID
48-49	Job Number
50-55	Disk Segments in Program
56-61	User Charge Number
62-64	Core Required
65-66	Number of Files
67-68	Number of Disk Files
69	Execution Code
70	Reserved
71	Supplementary Execution Code
72	MCP Intrinsic Flag
73	Reserved
74-79	Date Compiled
80-99	Reserved

Figure 2. End of Job and Beginning of Job Records

COLLECTION OF JOB-ORIENTED DATA

Detailed Format

The job summary record in Figure 3 consists of performance variables of interest for a workload characterization. A job record to be used for another purpose, e.g., billing reports, would probably embody a significantly different set of information. The Log ID Number, Job Start Time, and Core Required fields are taken from BOJ record type 6, Figure 2. EOJ record type 2, Figure 2, yields Job End Time, Direct Processor Time, Prorated Processor Time, Hardware Type, and job Log ID. Elapsed Time is computed using EOJ and BOJ times taken from type 2 and type 6 records respectively. The remaining fields itemizing files, devices, channels, and block counts are taken from the file close records, type 0, Figure 1.

Method

Each event-oriented record is read in the order it was created and checked for type 6, the BOJ record. A new BOJ record defines a unique job identifier by means of the Log ID Number. All subsequent records pertaining to a particular job are found by using this identifier. As each job starts it is added to the mix and with each EOJ the job is removed by updating the mix count. All file open and close records for a particular job are processed by counting the number of different files, devices, and channels that appear and by breaking down the block count into file, device, and channel subtotals. The EOJ record finishes the summary cycle for a job. The processor time is extracted from this final record and the completed job summary record of Figure 3 is recorded. Table I shows a partial list of summary records created by processing one month of raw accounting data.

WORKLOAD CHARACTERISTICS

The system dependent characteristics of a month's workload processed by B 3500 were analyzed in order to determine the test workload

Position	Length (Bytes)	Data Type	Contents
0-2	3	PD	Log ID Number
3-7	5	PD	Job Start (msecs)
8-12	5	PD	Job End Time (msecs)
13-17	5	PD	Elapsed Time (msecs)
18-22	5	PD	Direct Processor Time (msec)
23-27	5	PD	Prorated Processor Time (msec)
28-32	5	PD	Total Processor Time (msec)
33-34	2	PD	Core Required (kilo-bytes)
35-39	5	PD	Total Block Count
40-41	2	B	Number of Files (L)
42-43	2	B	Number of Devices (M)
44-45	2	B	Number of Channels (N)
46-V	L x 6	CH	File Names
V	M x 2	PD	Device Types
V	N x 2	PD	Channels
V	M x 2	B	Files per Device
V	N x 2	B	Files per Channel
V	N x 2	B	Devices per Channel
V	L x 5	PD	Blocks per File
V	M x 5	PD	Blocks per Device
V	N x 5	PD	Blocks per Channel

Key: PD - Packed Decimal
B - Binary
CH - CHaracter
L - Number of Files
M - Number of Devices
N - Number of Channels
V - Variable

Figure 3. Job Summary Record Used in Workload Characterization

LOG ID NO	START TIME	END TIME	ELAPSED TIME	DIRECT TIME	PRORATED TIME	BLK COUNT	CORE REQ (K BYTES)	NO OF FILES	NO OF DEVICES	NO OF CHANNELS
60	33604.523	33607.482	2.959	0.290	0.276	2	2	1	1	1
42	33345.133	33744.499	399.366	12.528	31.103	95	29	2	2	1
43	33454.392	33752.406	298.014	33.339	22.142	266	29	2	2	1
61	33618.921	33889.455	270.534	9.515	24.390	883	4	5	2	2
62	33764.080	34268.236	504.156	144.085	35.795	6235	23	10	2	2
63	33819.293	34293.600	474.307	53.349	35.741	6197	4	16	2	2
65	34364.520	34705.627	341.107	42.877	18.519	4961	4	6	2	2
64	34310.846	34823.387	512.541	211.895	33.017	6973	23	16	2	2
66	34825.086	34962.730	137.644	4.195	15.699	371	4	3	2	2
67	34888.316	35407.028	518.712	264.571	43.563	8926	23	10	2	2
69	35606.039	35813.455	207.416	3.527	16.279	2	16	2	2	2
68	35562.663	36088.008	525.345	203.484	31.321	3973	23	16	2	2
70	35847.326	36316.318	468.492	83.533	40.269	1322	29	3	3	2
71	36324.461	36423.194	98.733	10.813	13.636	1215	4	4	2	2
72	36552.199	36613.953	61.754	3.100	3.643	271	3	2	2	2
73	36615.653	36705.637	89.984	3.143	13.041	284	4	3	2	2
75	37286.357	37373.372	87.015	12.802	3.470	407	19	9	3	2
76	37372.496	37399.801	27.305	10.400	[illegible]	444	11	2	2	1
78	37562.728	37665.775	3.047	3.401	0.099	2	4	1	1	1
80	37764.265	37797.390	33.125	0.390	1.079	52	4	1	1	1
79	37677.667	37816.245	138.578	21.219	3.503	2512	4	4	2	2
82	37930.256	38026.668	96.412	3.275	5.076	2	16	2	2	2
81	37815.595	38183.709	368.114	35.359	17.321	1321	15	9	4	3
83	38196.704	38354.873	158.169	17.430	3.224	1961	4	4	2	2
84	38473.748	38531.257	57.509	18.054	1.407	226	15	7	3	3
85	38873.498	38880.823	7.325	1.204	0.225	99	4	2	2	2
86	38894.513	38910.257	15.744	3.514	0.357	181	15	5	2	2
87	38918.644	38946.645	28.001	1.308	1.228	93	5	2	2	2
74	36854.698	39156.227	2301.529	1049.657	149.570	54004	15	13	2	2
88	39144.588	39696.739	552.151	268.309	7.323	12998	16	47	4	3
89	39155.474	39750.491	595.017	265.803	8.761	8730	23	18	2	2
92	39839.309	39956.312	117.003	0.721	1.042	19	4	3	2	2
94	39953.109	39969.613	16.504	1.666	0.726	42	20	5	1	1
95	39970.233	39982.044	11.805	0.936	0.581	19	19	3	2	2
98	40042.494	40050.971	8.477	0.521	0.304	1	3	2	2	2
99	40115.681	40238.402	122.721	7.350	9.519	639	3	2	2	2
90	39715.837	40274.246	558.409	103.669	23.961	747	29	5	3	1
96	39979.468	40325.901	346.433	2.413	23.263	38	20	5	1	1
97	40326.374	40329.480	3.106	0.106	0.350	7	4	1	1	1
100	40391.277	40408.072	16.795	3.098	1.862	19	4	3	2	2
101	40406.513	40417.215	10.702	1.739	1.045	42	20	5	1	1
102	40417.739	40425.664	7.925	0.757	0.042	20	19	4	3	2
103	40549.381	40577.462	28.081	2.649	1.703	51	15	5	2	1
107	40572.469	40584.089	11.620	1.555	0.782	122	2	2	2	2
108	40592.046	40603.344	11.298	1.024	0.037	122	2	2	2	2
109	40607.861	40673.751	65.950	4.936	5.239	394	4	5	2	2
104	40549.708	40693.009	140.301	3.435	11.451	11	4	2	2	2
105	40550.252	40701.218	150.966	1.033	11.800	8	15	4	2	2
106	40550.591	40707.412	156.821	0.123	12.550	0	5	0	0	0
110	40749.234	40769.144	19.910	2.700	1.039	51	15	5	2	1
113	40794.921	40898.564	103.643	3.441	10.567	11	4	2	2	2
114	40908.858	40931.901	23.043	3.570	2.083	383	5	3	3	2
115	40979.013	41081.162	102.150	11.014	4.544	894	14	3	3	2
111	40762.602	41118.204	355.602	33.252	27.904	2341	29	13	3	3
112	41197.195	41203.833	6.638	1.002	0.320	216	3	2	2	2
119	41340.803	41390.215	49.412	7.491	2.900	450	15	7	3	2
116	41094.273	41526.041	431.768	11.007	35.410	1060	4	9	2	2

Table I -- Typical B 3500 Job Summary Records (Fixed portion only)

characteristics. Single variable histograms were constructed to isolate the major variables. The following histograms were studied:

(1) Direct Time
(2) I/O activities to disk
(3) I/O activities to tape
(4) Core used
(5) Number of files
(6) Number of channels

As an example, the histogram of the direct time is tabulated in Table II. Based on these histograms it was decided to characterize a job by the following four variables.

(1) Direct Time, seconds
(2) Number of block counts to disk
(3) Core used
(4) Number of files

The direct time is the demand placed on the CPU and is the processor time in the user state or the normal state (or the problem program state). The number of block counts is the number of blocks of data exchanged between main storage and the disk. The other two variables are self-explanatory. These four job-oriented characteristics were determined from the derived LOGGER summary data. The general method of the statistical analyses to determine the workload characteristics appears in Reference 3.

TEST WORKLOAD CHARACTERISTICS

The test workload characteristics were determined by matching the four-dimensional probability density of the test workload with that of the real workload. The details of this method appear in Reference 4 and will be briefly presented here.

SUMMARY OF CPU(DIRECT) TIME IN SECS.

XMIN=	0.0000	XMAX=	200.0000
AMIN=	0.0000	AMAX=	4365.7656
MEAN VALUE=	58.6307		
STD DEVIATION=	152.0641		
MAXIMUM FREQUENCY AT X=	0.0000 WITH	2011 JOBS	

HISTOGRAM OF CPU(DIRECT) TIME IN SECS.

INTERVAL	COUNT	DISTRIBUTION	DENSITY
0.0000	2011	0.250000	0.250000
2.0000	710	0.091293	0.349915
4.0000	455	0.058502	0.408432
6.0000	327	0.042050	0.450485
8.0000	262	0.033691	0.484177
10.0000	199	0.025589	0.509766
12.0000	176	0.022629	0.532394
14.0000	169	0.021591	0.554001
16.0000	161	0.020691	0.574707
18.0000	143	0.018387	0.593094
20.0000	122	0.015686	0.608795
22.0000	95	0.012207	0.621002
24.0000	89	0.011444	0.632446
26.0000	84	0.010788	0.643250
28.0000	89	0.011444	0.654694
30.0000	84	0.010735	0.665497
32.0000	87	0.011185	0.676697
34.0000	80	0.010284	0.686981
36.0000	57	0.007324	0.694305
38.0000	83	0.010666	0.704967
40.0000	67	0.008606	0.713593
42.0000	103	0.013245	0.726837
44.0000	53	0.006805	0.733658
46.0000	49	0.006287	0.739960
48.0000	35	0.004486	0.744461
50.0000	43	0.005524	0.750000
52.0000	37	0.004745	0.754745
54.0000	44	0.005646	0.760406
56.0000	36	0.004623	0.765045
58.0000	66	0.008484	0.773529
60.0000	44	0.005646	0.779190
62.0000	45	0.005783	0.784973
64.0000	36	0.004623	0.789597
66.0000	34	0.004364	0.793976
68.0000	42	0.005386	0.799377
70.0000	21	0.002686	0.802078
72.0000	27	0.003464	0.805542
74.0000	41	0.005264	0.810822
76.0000	34	0.004364	0.815186
78.0000	30	0.003845	0.819045
80.0000	34	0.004364	0.823425

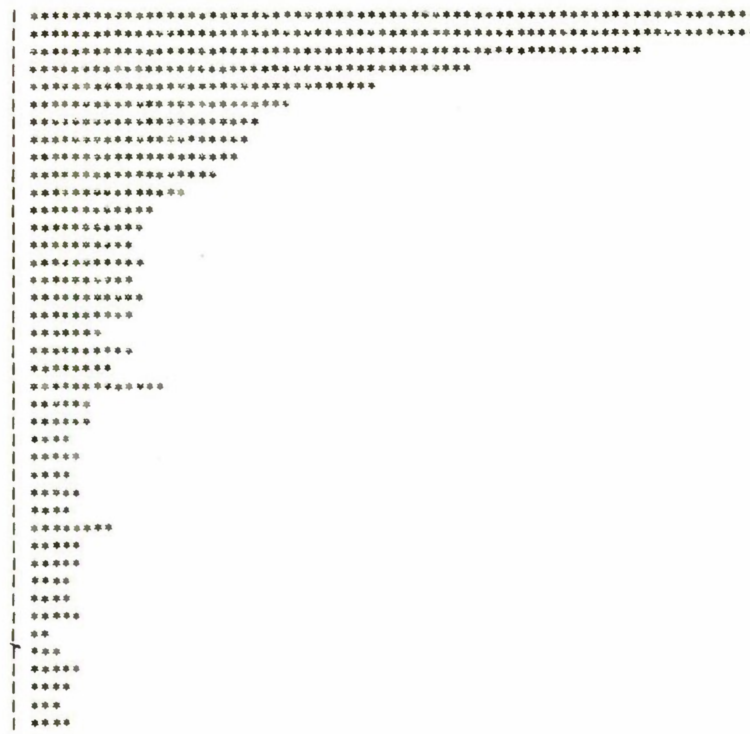

Table II -- Histogram of Processor Time

82.0000	36	0.004023	0.828049	| ****
84.0000	31	0.003933	0.832047	| ***
86.0000	37	0.004745	0.836792	| ****
88.0000	27	0.003464	0.840271	| ***
90.0000	21	0.002686	0.842972	| **
92.0000	31	0.003965	0.846954	| ***
94.0000	26	0.003342	0.850296	| ***
96.0000	13	0.001663	0.851974	| *
98.0000	25	0.003204	0.855174	| ***
100.0000	22	0.002823	0.858017	| **
102.0000	28	0.003586	0.861618	| ***
104.0000	24	0.003082	0.864700	| ***
106.0000	16	0.002045	0.866750	| **
108.0000	13	0.001663	0.868437	| *
110.0000	16	0.002045	0.870499	| **
112.0000	18	0.002304	0.872803	| **
114.0000	21	0.002686	0.875504	| **
116.0000	17	0.002182	0.877680	| **
118.0000	17	0.002182	0.879852	| **
120.0000	12	0.001541	0.881424	| *
122.0000	14	0.001785	0.883224	| *
124.0000	22	0.002823	0.886047	| **
126.0000	20	0.002563	0.888626	| **
128.0000	19	0.002441	0.891068	| **
130.0000	11	0.001404	0.892487	| *
132.0000	18	0.002304	0.894791	| **
134.0000	20	0.002563	0.897359	| **
136.0000	9	0.001144	0.898527	| *
138.0000	13	0.001663	0.900192	| *
140.0000	21	0.002686	0.902793	| **
142.0000	17	0.002182	0.905090	| **
144.0000	14	0.001785	0.906871	| *
146.0000	22	0.002823	0.909714	| **
148.0000	11	0.001404	0.911133	| *
150.0000	18	0.002304	0.913437	| **
152.0000	6	0.000763	0.914215	|
154.0000	7	0.000885	0.915115	|
156.0000	14	0.001785	0.916916	| *
158.0000	9	0.001144	0.918070	| *
160.0000	13	0.001663	0.919737	| *
162.0000	15	0.001923	0.921677	| *
164.0000	10	0.001282	0.922959	| *
166.0000	9	0.001144	0.924118	| *
168.0000	2	0.000244	0.924377	|
170.0000	6	0.000763	0.925140	|
172.0000	8	0.001022	0.926179	| *
174.0000	6	0.000763	0.926941	|
176.0000	7	0.000885	0.927841	|
178.0000	7	0.000885	0.928741	|
180.0000	2	0.000244	0.929001	|
182.0000	9	0.001144	0.930161	| *
184.0000	7	0.000885	0.931061	|
186.0000	6	0.000763	0.931839	|
188.0000	7	0.000885	0.932739	|
190.0000	6	0.000763	0.933502	|
192.0000	4	0.000504	0.934021	|
194.0000	1	0.000122	0.934143	|
196.0000	3	0.000381	0.934540	|
198.0000	7	0.000885	0.935440	|
200.0000	502	0.064545	1.000000	| **

Table II -- Histogram of Processor Time (Continued)

The B 3500 workload is characterized by the following four variables.

X_1 - Number of files
X_2 - Core used
X_3 - Direct time
X_4 - Number of block counts to disk

A job, therefore, may be regarded as a point in the multi-dimensional space, with the co-ordinates representing each of the four demands. The workload then becomes an ensemble of points in this co-ordinate system.

In general, if X_1, X_2, X_3, and X_4 are the four variables used to describe the workload and N_{ijkl} is the number of jobs in the cell* with co-ordinates $X_1 = x_1^{(i)}$, $X_2 = x_2^{(j)}$, $X_3 = x_3^{(k)}$, $X_4 = x_4^{(l)}$ then the workload can be described as a multi-variate probability density function and its value is given by:

$$p_{ijkl} = \frac{N_{ijkl}}{N_{tot}} \qquad i, j, k, l = 1, 2, 3 \ldots L \qquad (2.1)$$

where p_{ijkl} is the probability of finding a job in the (i-j-k-l)-th cell and N_{tot} is the total number of jobs in the workload. L is the number of cells along each co-ordinate axis.

The test workload is constructed by matching the joint probability density of the four variables for the test workload with that of the

---

* The magnitude of the variable corresponding to each cell is taken to be its value at the mid-point of the interval.

real workload. Denoting the test workload characteristics by primed quantities, we have

$$N'_{ijkl} = p_{ijkl} \; N'_{tot} \tag{2.2}$$

This equation can be physically interpreted as matching the joint probability density of the test workload with that of the real workload. Constraints on the total number of jobs in the test workload or on the total CPU time for processing it, can be imposed in the determination of N'_{ijkl}. In this study the constraint was placed on the total CPU time, namely, 2000 seconds. The characteristics of the test workload are derived using equation (2.2) and they are tabulated in Table III. The test workload consists of 87 jobs.

The total number of cells used in the determination of p_{ijkl} and N'_{ijkl} is governed by the value of L, or the number of cells along each co-ordinate axis. In our study the value of $N_{tot} = 7776$. A very large value of L will result in a large value of the total number of cells (L^4). As seen from equation (2.1) there are L^4 values of p_{ijkl} (for example, p_{1111}, $p_{1112}, \ldots, p_{2222}, \ldots, p_{LLLL}$). Since the total number of jobs (N_{tot}) in the ensemble is fixed, large values of L result in small values of p_{ijkl}. It should be pointed out that there is a rounding-off performed in determining the N'_{ijkl} from equation (2.2). If the value of N'_{ijkl} is less than 0.5 it will be rounded-off to 0. A large value of L will tend to diffuse the distribution and will result in a multi-dimensional picture that is not useful in describing the workload. Before selecting L the single variable histograms should be studied to determine the values of the variables that correspond to the most frequently occurring jobs. It is also not necessary to choose the same value of L along all the co-ordinate axes. The number and location of the cells is influenced by the single variable histograms. Based on these considerations the ensemble in

Table III

Characteristics of the Test Workload

Group	Number of Jobs (N_{ijkl})	Core (K-bytes)	Number of Files	CPU (sec.)	Block Count
1	14	4.5	3	2	25
2	4	4.5	3	4	200
3	5	4.5	3	5	200
4	2	4.5	3	9	1000
5	2	4.5	3	29	1000
6	1	4.5	3	73	5000
7	1	4.5	6	6	200
8	1	4.5	6	9	1000
9	1	4.5	6	31	1000
10	1	4.5	6	43	5000
11	1	6.5	11	33	1000
12	1	6.5	11	81	5000
13	5	17.5	3	3	25
14	3	17.5	3	6	200
15	1	17.5	3	9	1000
16	3	17.5	3	34	1000
17	1	17.5	3	78	5000
18	1	17.5	6	1	25
19	2	17.5	6	6	25
20	4	17.5	6	7	200
21	1	17.5	6	11	1000
22	5	17.5	6	31	1000
23	2	17.5	6	77	5000
24	2	18.0	11	7	200
25	6	18.0	11	34	1000
26	1	18.0	11	41	5000
27	1	18.0	11	75	1000
28	6	18.0	11	74	5000
29	1	29.5	3	4	25
30	2	29.5	3	30	200
31	1	29.5	6	8	200
32	1	29.5	6	30	1000
33	1	29.5	6	81	5000
34	1	30.0	11	29	1000
35	2	30.0	11	72	5000

this study was divided into 144 cells by choosing 3 values of the number of files, 3 values for the core size, 4 values for the direct time, and 4 values for the block count to disk. Table IV tabulates the 144 values for P_{ijkl}.

SYNTHETIC WORKLOAD

The eighty-seven jobs in the test workload are realized by using a synthetic program. A COBOL program was designed and implemented for this purpose. It is not practical to use one synthetic program that covers a large range of variation in core size and number of files; further such a synthetic program will not be flexible. It is simple and easy to implement several synthetic programs to represent the core size and the number of files which are specified as compile time parameters. The four variables to be represented are divided into two groups. They are:

Run time variables - Direct time and number of block counts to disk.

Compile time variables - Core size and number of files.

Two parameters were built into the synthetic program for varying the direct time and the number of block counts to disk. There are nine combinations of core size and the number of files and nine separate COBOL programs were compiled to reflect these nine combinations. The nine programs were stored in auxiliary storage, retrieved at run time and executed using the run time parameters.

CALIBRATION AND INVERSION

The nine values of the core size and number of files combinations were made equal to the corresponding values of the test workload. This eliminated the need for calibrating the synthetic program for these two parameters. Each one of the nine programs has two parameters for varying the direct time and the number of block counts

I - CORE
J - FILES
K - CPU
L - IO

I = 4, J = 3

K \ L	25		200		1000		5000	
1000	1056	.136	282	.036	0	.000	0	.000
6000	29	.004	372	.048	189	.024	0	.000
30000	4	.001	10	.001	164	.021	56	.007
72000	2	.000	0	.000	30	.004	102	.013

I = 4, J = 6

K \ L	25		200		1000		5000	
1000	23	.003	7	.001	0	.000	0	.000
6000	1	.000	100	.013	97	.012	0	.000
30000	0	.000	1	.000	103	.013	67	.009
72000	0	.000	0	.000	0	.000	56	.007

I = 4, J = 11

K \ L	25		200		1000		5000	
1000	1	.000	0	.000	0	.000	0	.000
6000	0	.000	21	.003	19	.002	0	.000
30000	0	.000	1	.000	85	.011	53	.007
72000	0	.000	0	.000	0	.000	92	.012

Table IV -- Joint Probability Distribution of the Real Workload. For example, the pair of numbers (1056, 0.136) for I = 4, J = 3, K = 1000, L = 25 represent N_{ijkl} and P_{ijkl} respectively.

I - CORE
J - FILES
K - CPU
L - IO

I = 17
J = 3

K \ L	25		200		1000		5000	
1000	412	.053	35	.004	0	.000	0	.000
6000	17	.002	198	.025	73	.009	0	.000
30000	3	.000	48	.006	194	.025	13	.002
72000	9	.001	1	.000	36	.005	80	.010

I = 17
J = 5

K \ L	25		200		1000		5000	
1000	95	.011	10	.001	0	.000	0	.000
6000	125	.016	325	.042	64	.008	0	.000
30000	0	.000	49	.006	366	.047	56	.007
72000	0	.000	1	.000	30	.004	165	.021

I = 17
J = 11

K \ L	25		200		1000		5000	
1000	0	.000	0	.000	0	.000	0	.000
6000	11	.001	139	.018	34	.004	0	.000
30000	0	.000	15	.002	474	.061	109	.014
72000	0	.000	0	.000	67	.009	501	.064

Table IV -- Joint Probability Distribution of the Real Workload (Continued)

I - CORE
J - FILES
K - CPU
L - IO

I= 29, J= 3

K \ L	25		200		1000		5000	
1000	84	.011	10	.001	0	.000	0	.000
6000	11	.001	28	.004	2	.000	0	.000
30000	38	.005	161	.021	53	.007	0	.000
72000	12	.002	3	.000	56	.007	17	.002

I= 29, J= 5

K \ L	25		200		1000		5000	
1000	7	.001	0	.000	0	.000	0	.000
6000	10	.001	61	.008	6	.001	0	.000
30000	1	.000	14	.002	56	.007	0	.000
72000	1	.000	11	.001	47	.006	62	.008

I= 29, J= 11

K \ L	25		200		1000		5000	
1000	0	.000	0	.000	0	.000	0	.000
6000	3	.000	17	.002	0	.000	0	.000
30000	0	.000	7	.001	70	.009	2	.000
72000	0	.000	0	.000	33	.004	125	.016

Table IV -- Joint Probability Distribution of the Real Workload (Continued)

to disk. Seventy-five calibration runs were conducted to relate these two parameters to the direct time and the block count. In all these calibration runs the LOGGER summary data was used to determine the block count and the direct time. Various combinations of the four parameters, viz., core size, number of files, and the parameters for direct time and the block count were used in these calibration experiments. Table V presents these experimental results.

These experimental results are used in the inversion of the test workload characteristics into synthetic program parameters. During the calibration experiments, the synthetic program parameters are varied over the required range and the resulting values of the direct time and the number of block counts are obtained from the LOGGER summary data. Inversion consists of reversing the above procedure. In other words, given a set of workload characteristics, (direct time and the number of block counts) the required values of the synthetic program parameters are determined from the calibration results. In this study because of the number of variables involved, no attempt was made to derive general expressions relating the synthetic program parameters with the workload characteristics. Instead the calibration runs were conducted with the values of the parameters in the immediate neighborhood of the desired workload characteristics. The experimental results were used to determine the parameter settings for the 87 jobs in the test workload. The synthetic workload is the collection of these 87 jobs.

CLOSURE

The performance of a computer system can be described in terms of the interaction between the workload and the hardware-software configuration. A method of studying this interaction is to conduct experiments with the existing hardware-software configuration using a stabilized, reproducible workload that is representative of the

Table V

Experimental Results Used in Calibrating the Synthetic Program

Job No.	Synthetic Program Parameters: Compile Time: Core (i)	Files (j)	Run Time: Times thru CPU loop (k)	Total Block Count (l)	Calibration Results: Core (K-bytes) (i)	Files (j)	CPU (sec) (k)	Block Count (l)
1	4	3	100	25	4.5	3	1	25
2	4	3	100	200	4.5	3	3	200
3	4	3	300	1000	4.5	3	11	1000
4	4	6	1000	200	4.5	6	11	200
5	4	6	800	5000	4.5	6	49	5000
6	4	11	3000	1000	6.5	11	37	1000
7	17	3	100	25	17.5	3	2	25
8	17	3	300	1000	17.5	3	11	1000
9	17	3	10000	5000	17.5	3	139	5000
10	17	6	600	25	17.5	6	8	25
11	17	6	500	1000	17.5	6	13	1000
12	17	6	4000	5000	17.5	6	82	5000
13	17	11	800	200	18.0	11	13	200
14	17	11	1000	5000	18.0	11	41	5000
15	17	11	4000	5000	18.0	11	89	5000
16	29	3	100	25	29.5	3	6	25
17	29	3	2500	200	29.5	3	28	200
18	29	3	5000	25	29.5	3	46	25
19	29	6	10	200	29.5	6	2	200
20	29	6	800	200	29.5	6	12	200
21	29	6	4000	5000	29.5	6	86	5000
22	29	11	4000	5000	30.0	11	84	5000
23	29	11	15000	1000	30.0	11	146	1000
24	4	3	100	25	4.5	3	2	25
25	4	3	50	200	4.5	3	4	200
26	4	3	300	200	4.5	3	5	200
27	4	3	50	1000	4.5	3	9	1000
28	4	3	2500	1000	4.5	3	37	1000
29	4	3	3200	5000	4.5	3	77	5000
30	4	6	300	200	4.5	6	6	200
31	4	6	50	1000	4.5	6	10	1000
32	4	6	2500	1000	4.5	6	36	1000
33	4	6	100	5000	4.5	6	45	5000
34	4	11	2500	1000	6.5	11	38	1000
35	4	11	3000	5000	6.5	11	72	5000
36	17	3	70	25	17.5	3	1	25
37	17	3	100	200	17.5	3	3	200

Table V

Experimental Results Used in Calibrating the Synthetic Program

(Continued)

Job No.	Synthetic Program Parameters: Compile Time: Core (i)	Files (j)	Run Time: Times thru CPU loop (k)	Total Block Count (l)	Calibration Results: Core (K-bytes) (i)	Files (j)	CPU (sec) (k)	Block Count (l)
38	17	3	10	1000	17.5	3	10	1000
39	17	3	2000	1000	17.5	3	32	1000
40	17	3	4000	5000	17.5	3	76	5000
41	17	6	10	25	17.5	6	2	25
42	17	6	400	25	17.5	6	6	25
43	17	6	100	200	17.5	6	4	200
44	17	6	10	1000	17.5	6	9	1000
45	17	6	2000	1000	17.5	6	30	1000
46	17	6	3000	5000	17.5	6	72	5000
47	17	11	100	200	18.0	11	5	200
48	17	11	2300	1000	18.0	11	33	1000
49	17	11	500	5000	18.0	11	47	5000
50	17	11	6500	1000	18.0	11	76	1000
51	17	11	3000	5000	18.0	11	75	5000
52	29	3	10	25	29.5	3	2	25
53	29	3	2600	200	29.5	3	28	200
54	29	6	400	200	29.5	6	7	200
55	29	6	3000	1000	29.5	6	48	1000
56	29	6	3000	5000	29.5	6	74	5000
57	29	11	3000	1000	30.0	11	38	1000
58	29	11	3000	5000	30.0	11	72	5000
59	4	3	0	200	4.5	3	4	200
60	4	3	0	1000	4.5	3	9	1000
61	4	3	2000	1000	4.5	3	29	1000
62	4	3	3000	5000	4.5	3	73	5000
63	4	6	0	1000	4.5	6	9	1000
64	4	6	2000	1000	4.5	6	31	1000
65	4	6	0	5000	4.5	6	43	5000
66	4	11	2000	1000	6.5	11	33	1000
67	17	3	400	200	17.5	3	6	200
68	17	3	0	1000	17.5	3	9	1000
69	17	6	350	200	17.5	6	7	200
70	17	6	0	1000	17.5	6	11	1000
71	17	11	300	200	18.0	11	7	200
72	17	11	2000	1000	18.0	11	34	1000
73	17	11	0	5000	18.0	11	41	5000
74	29	6	2000	1000	29.5	6	30	1000
75	29	11	2000	1000	30.0	11	29	1000

real workload. That there is a need for constructing a representative test workload need not be overemphasized. In this study the representative workload is constructed by first isolating the most frequently occurring jobs.

The accounting package seldom captures data about the human factors involved, e.g., time for mounting and dismounting tapes. Special measurements have to be made to determine the human factors. Typical measurements are the number of frequently used tapes, and the method of tape assignments.

The following procedure may be adopted for evaluating the performance of a computer system in which tape files dominate. The workload can be divided into two distinct classes - jobs with disk I/O only and jobs with tape and/or disk I/O. The former class can be represented using methods described in this section. The latter class can be represented with the use of synthetic programs that create tape files. The combined representative synthetic workload can then be used to study the effects of system parameters; for example, changes in the configuration, addition to the existing configuration, blocking factor etc. In these experiments care should be taken to insure that the human factors are adequately simulated by introducing known amounts of delay in mounting and dismounting tapes.

SECTION III

EXPERIMENTS WITH THE TEST WORKLOAD

PURPOSE

A computer system can be considered as a hardware-software-configuration (HSC) interacting with its workload. Evaluation of computer system performance requires an understanding of this interaction in order to assess and improve the performance and to predict the effects of changes in either the workload or the HSC.

In this study, experiments were conducted with the B 3500 using a representative model of the real workload. The controlled experiments were conducted in a dedicated environment. A hardware monitor (DYNAPROBE) was used to measure the utilization of the processor, the channel and the physical devices.

EXPERIMENTAL RESULTS

The test workload, representative of the batch jobs processed during a month on the B 3500 (ESD, Hanscom Air Force Base) consisted of 87 jobs. Their CPU time, core used, number of files and block count to disk are presented in Table III. LOGGER data was used to obtain the following characteristics for each job.

a) Start Time
b) Stop Time
c) Direct time used
d) Core requested
e) Number of files
f) Block count per file

A hardware monitor, DYNAPROBE 7900, was used to measure the following quantities.

a) CPU busy in the normal state

b) CPU idle

c) Disk channel 2 busy (primary)

d) Disk channel 10 busy (alternate)

e) Disk channels 2 and 10 busy

Figure 4 is a schematic of the hardware configuration used in these experiments. The electrical signals corresponding to the above quantities were recorded on tape which was later analyzed to determine the utilization values.

The architecture of the B 3500 was initially studied to determine the nature of the experiments to be performed. In this system there are six disk units connected to the processor by a pair of channels (channel 2 and 10) to achieve simultaneity. The disk units are head-per-track units. As there is only one primary channel (channel 2) for all the disk units, overlap between data transfers can be accomplished by forcing the transfer to take place through the secondary channel (channel 10). Because of this channel - disk unit relationship it is not possible to initiate many data transfers, analogous to parallel seeks characteristic of moving arm disk units.

The degree of multiprogramming, the number of jobs co-resident in main memory, is determined mainly by the core size of the available jobs in the mix. In the experiments reported here, all the jobs were initially spooled to the disk. The first set of jobs were initiated. The number of jobs in this set was determined by the individual core sizes. At the termination of a job, the operating system scans the list of available jobs and initiates a job which can fit into the vacant core space. If such a job cannot be found the operating system waits for a second job to terminate and the search for

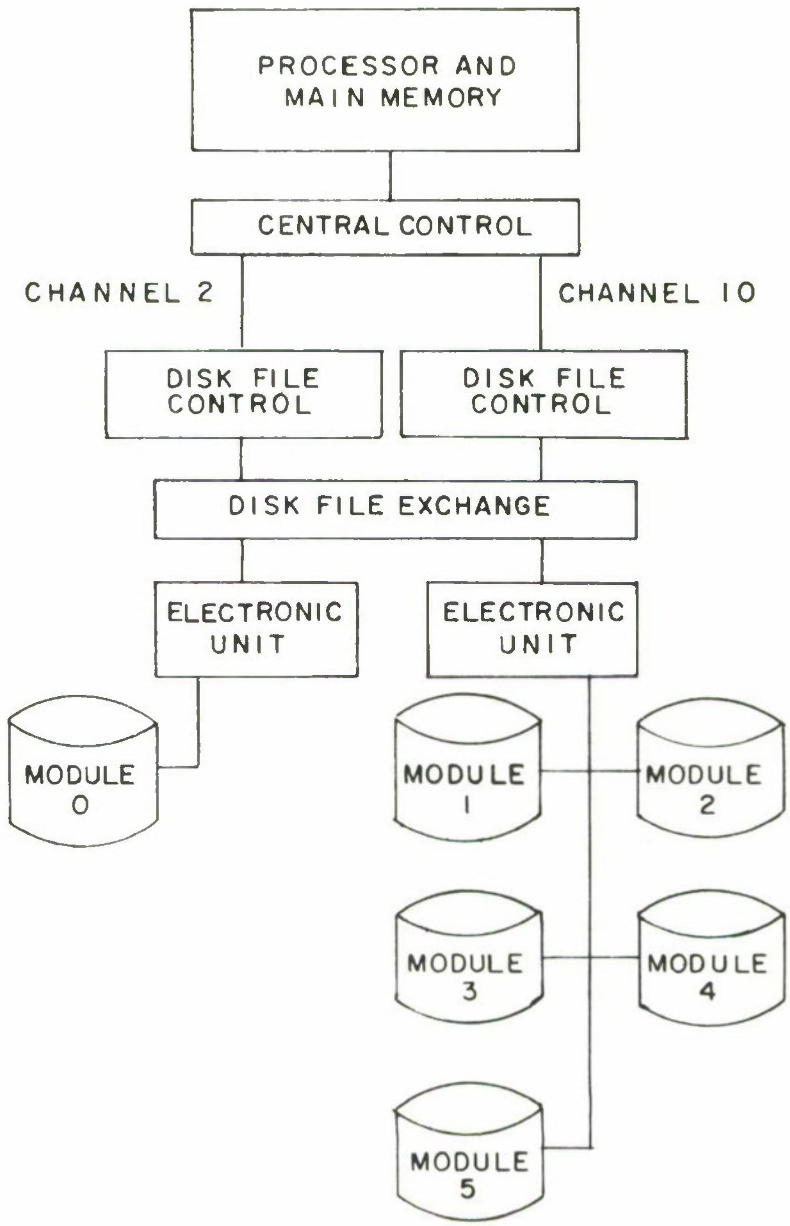

Figure 4. B-3500 HARDWARE CONFIGURATION

the next job is repeated with the difference that the vacant space now available has increased. For this reason the degree of multiprogramming varies during a session. The multiprogramming (number of jobs in the mix) resulting from one of the experimental sessions is shown in Figure 5.

Eight runs were conducted using the test workload. The effect of external sequencing (i.e., the order in which the jobs are processed by the system) on the overall performance of the computer system was studied. The first experiment was run single-thread to verify the characteristics of the test workload. The second experiment was run with multiprogramming in which the jobs were initiated from the operator's console after every job termination. This was found to be inefficient as the system was idling waiting for jobs to be initiated. In the third experiment the job initiating was accomplished automatically by the operating system with no operator intervention. It was found that changes in the external sequencing have no appreciable effect on the overall performance. This is not very suprising in view of the fact that the workload is CPU-bound. In single processor, multiprogrammed systems, CPU-bound workloads lead to a situation in which all the jobs have to wait to use the processor, since the overlap between the processor and I/O usage is very small.

The test workload used only disk files and the I/O activities were, therefore, much faster than the equivalent I/O activities to tape. In effect, the I/O load on the system was reduced and the test workload was made CPU-bound. This is confirmed by the fact that overall CPU utilization of the month's workload studied was approximately 25% and the CPU utilization of the test workload was approximately 65%. It was necessary to adjust the I/O load on the system so that the CPU utilization became reasonable.

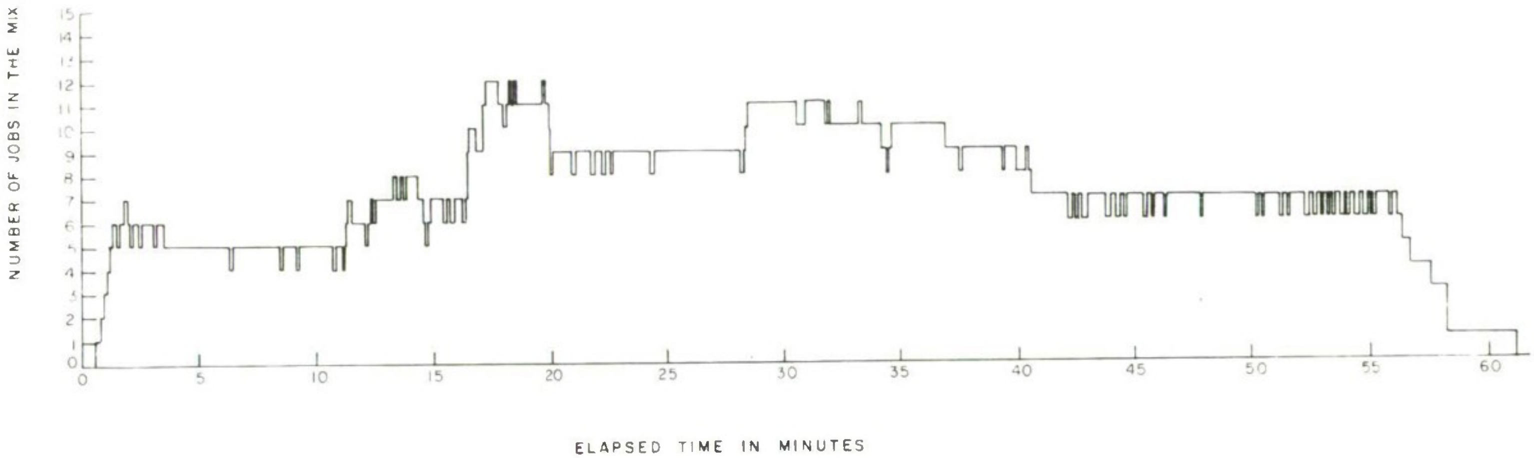

Figure 5. VARIATION OF THE DEGREE OF MULTIPROGRAMMING DURING EXPERIMENT 4

The synthetic workload used allows for adjustment of the I/O load by means of the I/O run time program parameter. The assumption is made that increasing the I/O load will bring the CPU utilization down to a value approaching that observed for the real workload. This implies that the neglected tape I/O activities can be replaced by a suitable number of disk I/O activities. The I/O control parameter for all the jobs in the test workload was increased by a factor of 5. The result was that the elapsed time of the experiment became too large. Only 36 of the total of 87 jobs were completed in slightly more than 2 hours. The number of block counts was then increased by a factor of 2 and the resulting processor utilization was found to be 45.8%. In both these experiments it was found that replacing the tape I/O with disk I/O led to large values of channel utilization. In trying to decrease the CPU utilization to realistic values we were in effect increasing the channel utilization beyond the realistic values. In real life situations the tape drives and disk drives are connected through separate channels and it is not possible to study the behaviour of such a system by using a test workload that places the total I/O load on any one of the channels. The overall summary of experimental results is shown in Table VI.

HARDWARE MONITORING

A hardware monitor, DYNAPROBE 7900*, is used to measure the resource utilization of the major resources during the controlled experiments. The hardware monitor is a high impedance meter that measures the electrical signals that correspond to the busy or the idle state of a given resource. The hardware monitor, because of its high impedance, does not perturb the system being measured. This is a decided advantage over software monitors which influence the performance of the system being measured. The hardware monitor

*Comress, Incorporated.

Table VI

Overall Summary of the Experimental Results

Experiment Number	Elapsed Time (sec.)	Processor Time (sec.)	Total Block Count	CPU Utilization	Remarks
1	6896	1794	110,775	26.0%	87 jobs, single thread, structured schedule.
2	3344	1994	110,750	59.6%	86 jobs, multi-programming by executing jobs from operator's console; structured schedule.
3	3025	2034	110,750	67.2%	86 jobs, multi-programming with MCP scheduling and executing the jobs; structured schedule.
4	3682	2071	110,775	56.2%	87 jobs, multi-programming (same as Exp. 3), unstructured schedule.
5	7726	2669	216,733	34.5%	36 jobs, 8 partial jobs, multi-programming (same as Exp. 3), unstructured schedule, increased I/O by factor of 5.
6	5825	2666	202,100	45.8%	74 jobs, incomplete run, multi-programming (same as Exp. 3), unstructured schedule, doubled I/O activity.
7	6396	2937	221,550	45.9%	87 jobs, same as Exp. 6
8	5127	2936	221,550	57.3%	87 jobs, multi-programming (same as Exp. 3), structured schedule, doubled I/O activity.

captures the state of the various system resources continuously and its output is written out to tape. The hardware monitor is capable of measuring the state of a large number of system resources simultaneously, by means of hardware probes that are connected to the appropriate pins in the computer. These probe signals can be combined (logically) to determine the degree of overlap. The hardware monitor output is collected and later analyzed by means of special software routines to determine the utilization values.

The following were measured using the hardware monitor.

1) Processor busy in the normal state
2) Processor idle
3) Channel 2 busy
4) Channel 10 busy
5) Channel 2 and channel 10 busy

At the end of the experiment the output tape is analyzed by a special software package. The output of this program appears in Table VII. The program calculates two sets of utilization for the resources indicated in the table. The first value is the value for the interval. The second value is the cumulative value for the duration of the test period. The cumulative values of the utilization are used for the purpose of comparison with the corresponding values calculated from the accounting data.

```
I------------------------------------------------------------------------------------------------------------------I
I                                                                            FROM 23.25.10.0 TO 23.26.00.0        I
I                                                                                                                 I
I COUNTER  DESCRIPTION        (BASE = T01)          TOTALS FOR LAST      50.0 SECONDS    ACCUM. TOTALS FOR     5210.0 SECONDS I
I                                                                                                                 I
I   C01    NORMAL STATE                               3.3375434 SEC     6.58 PCT           3194.0314938 SEC    61.31 PCT I
I   C02    MCP IDLE LOOP                             46.2411553 SEC    92.49 PCT           1778.4329957 SEC    34.13 PCT I
I   C03    CHANNEL 2 BUSY  PRIMARY                     .1102093 SEC      .22 PCT           4017.2365858 SEC    77.11 PCT I
I   C04    CHANNEL 10 BUSY ALTERNATE                  0.0000000 SEC     0.00 PCT           3678.2100433 SEC    70.60 PCT I
I   C05    CHANNELS 2 AND 10 BUSY  %OVERLAP<          0.0000000 SEC     0.00 PCT           2793.5481359 SEC    53.62 PCT I
I   C06    EU0 1ST 50K ADDRESSES BUSY                  .1002082 SEC      .20 PCT            922.3805906 SEC    17.72 PCT I
I   C07    EU0 2ND 50K ADDRESSES BUSY                 0.0000000 SEC     0.00 PCT            131.9830765 SEC     2.53 PCT I
I   C08    EU0 3RD 50K ADDRESSES BUSY                 0.0000000 SEC     0.00 PCT            148.1744987 SEC     2.84 PCT I
I   C09    EU0 4TH 50K ADDRESSES BUSY                 0.0000000 SEC     0.00 PCT           2979.3596252 SEC    57.19 PCT I
I   C10    EU1 MOD 1 ACTIVE TIME                      0.0000000 SEC     0.00 PCT            187.1171334 SEC     3.59 PCT I
I   C11    EU1 MOD 2 ACTIVE TIME                      0.0000000 SEC     0.00 PCT            278.2072371 SEC     5.34 PCT I
I   C12    EU1 MOD 3 ACTIVE TIME                      0.0000000 SEC     0.00 PCT             71.7165456 SEC     1.38 PCT I
I   C13    EU1 MOD 4 ACTIVE TIME                      0.0000000 SEC     0.00 PCT               .0569673 SEC      .00 PCT I
I   C14    EU1 MOD 5 ACTIVE TIME                      0.0000000 SEC     0.00 PCT           2975.5540122 SEC    57.11 PCT I
I   C15    EU0 WITH CHANNEL 2 BUSY                     .1002083 SEC      .20 PCT           2548.3493245 SEC    48.91 PCT I
I   C16    EU1 WITH CHANNEL 2 BUSY                    0.0000000 SEC     0.00 PCT           1468.8065769 SEC    28.19 PCT I
I   T01    TOTAL ELAPSED TIME                        50.0000000 SEC   100.00 PCT           5210.0000000 SEC   100.00 PCT I
I   T02    PAUSE STATE                                0.0000000 SEC     0.00 PCT              0.0000000 SEC     0.00 PCT I
I   T03    STOP STATE                                 0.0000000 SEC     0.00 PCT              0.0000000 SEC     0.00 PCT I
I   001    CPU ACTIVE %NORMAL STATE & MCP<            3.7589447 SEC     7.52 PCT           3431.5670043 SEC    65.87 PCT I
I   002    CONTROL STATE %MCP & I/O CONTROL<           .4212953 SEC      .84 PCT            237.5355135 SEC     4.56 PCT I
I   003    CHANNEL 2 OVERLAP WITH CPU ACTIVE           .0075391 SEC      .02 PCT           2680.1169852 SEC    51.44 PCT I
I   004    CHANNEL 2 OVERLAP WITH CPU IDLE             .0926692 SEC      .19 PCT           1337.1190906 SEC    25.66 PCT I
I   005    CHANNEL 10 OVERLAP WITH CPU ACTIVE         0.0000000 SEC     0.00 PCT           2531.9738087 SEC    48.60 PCT I
I   006    CHANNEL 10 OVERLAP WITH CPU IDLE           0.0000000 SEC     0.00 PCT           1146.2362352 SEC    22.00 PCT I
I   007    CHANNEL 2 OR 10 BUSY                        .1002083 SEC      .20 PCT           4901.3964939 SEC    94.09 PCT I
I   008    CHANNEL 2 OR 10 OVERLAP WITH CPU ACTIVE     .0075391 SEC      .02 PCT           3271.7274783 SEC    62.80 PCT I
I   009    CHANNEL 2 OR 10 OVERLAP WITH CPU IDLE       .0926692 SEC      .19 PCT           1630.1710155 SEC    31.29 PCT I
I   010    CONTROL STATE OVERLAP WITH EU0 1ST FACE     .0075391 SEC      .02 PCT            634.1837668 SEC    12.17 PCT I
I   011    EU0 OVERLAP WITH SYSTEM ACTIVE              .0075391 SEC      .02 PCT           1743.0710290 SEC    33.55 PCT I
I   012    EU0 OVERLAP WITH SYSTEM IDLE                .0926692 SEC      .19 PCT            800.2782955 SEC    15.36 PCT I
I   013    EU1 OVERLAP WITH SYSTEM ACTIVE             0.0000000 SEC     0.00 PCT            932.0456891 SEC    17.89 PCT I
I   014    EU1 OVERLAP WITH SYSTEM IDLE               0.0000000 SEC     0.00 PCT             70.4201323 SEC     1.35 PCT I
I   015    SYSTEM ACTIVE%INC CPU & 2 OR 10 BUSY<      3.8515139 SEC     7.70 PCT           5061.7356195 SEC    97.15 PCT I
I   016    SYSTEM IDLE                               46.1484861 SEC    92.30 PCT            148.2519832 SEC     2.85 PCT I
I------------------------------------------------------------------------------------------------------------------I
I SYSTEM UTILIZATION %CPU WITH CHANNEL 2 OR 10 <                             FROM 23.25.10.0 TO 23.26.00.0        I
I                                                                                                                 I
I                                     10        20        30        40        50        60        70        80        90       100I
I DESCRIPTION / PERCENT OF T01         X         X         X         X         X         X         X         X         X         XI
I                             ***************************************************************************************************I
I                                                                                                                 I
I SYSTEM ACTIVE               XXXXXXXX .         .         .         .         .         .         .         .         .        .I
I                  (  7.70)            .         .         .         .         .         .         .         .         .        .I
I SYSTEM IDLE                          XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXI
I                  ( 92.30)            .         .         .         .         .         .         .         .         .        .I
I NORMAL STATE USER PGMS ONLY XXXXXXX  .         .         .         .         .         .         .         .         .        .I
I                  (  6.68)            .         .         .         .         .         .         .         .         .        .I
I CPU OVERHEAD                      X  .         .         .         .         .         .         .         .         .        .I
I                  (   .84)            .         .         .         .         .         .         .         .         .        .I
I 2/10 AND CPU ACTIVE                  .         .         .         .         .         .         .         .         .        .I
I                  (   .02)            .         .         .         .         .         .         .         .         .        .I
I 2/10 AND CPU IDLE                    .         .         .         .         .         .         .         .         .        .I
I                  (   .19)            .         .         .         .         .         .         .         .         .        .I
I------------------------------------------------------------------------------------------------------------------I
I------------------------------------------------------------------------------------------------------------------I
```

Table VII -- DYNAPROBE Hardware Monitor Reduction Output

SECTION IV

SUMMARY

Computer performance studies can be classified into two groups - assess and improve the performance; and predict the effects of changes in either the workload or the hardware-software configuration. Efforts in this area are greatly helped by a proper understanding of the interaction between the workload and the hardware-software-configuration. This report presents an approach that may be useful in understanding this interaction.

Experiments are performed with a Burroughs B 3500 computer system (ESD, Hanscom Air Force Base) using a synthetic test workload, in a dedicated environment. The method of constructing the test workload has been described. The method consists of matching the joint probability density of the real workload with that of the test workload. Direct time, I/O to disk, core size and the number of files are the four characteristics selected for representation. The magnitudes of these characteristics are derived from the LOGGER summary data.

In these controlled experiments the resource utilization is monitored using a hardware monitor. The values of the utilization calculated from the accounting data compare favorably with those measured by the monitor. This is a very significant finding of this study. This study has shown that the accounting data collected by the LOGGER is sufficient to calculate the processor and the channel utilization for the B 3500 computer system. LOGGER provides a ready and economical source of data for calculating the resource utilization that is very useful in analyzing the performance of the B 3500 system. A system manager can conveniently assess the system performance by periodic processing of the accounting data to determine the resource utilization.

The test workload used in these experiments does not include tape I/O activities. In installations where the tape I/O activities dominate, the synthetic workload experiments should be preceded by an analysis of the human factors involved. Some examples of these human factors are the layout of the tape library, the number of tapes in the library and the time taken for mounting and dismounting tapes. These human factors have a significant influence on the computer performance.

The tape I/O can be accounted for by creating tape files in the synthetic program. The workload can be divided into two distinct classes - jobs with disk I/O only and jobs with tape and/or disk I/O. The combined synthetic workload can then be used to study the effects of system parameters; for example, changes in the configuration, addition to the existing configuration, blocking factor etc.

Representative, synthetic workloads are not ends in themselves but just means to an end. They can be used as stabilized, reproducible workloads in conducting experiments with an existing hardware-software-configuration to evaluate the performance of the computer system. The synthetic workloads have the additional advantage that they are flexible. By varying the synthetic program parameters the characteristics of the test workload can be changed.

APPENDIX

CALCULATION OF THE RESOURCE UTILIZATION

The utilization of the processor and the I/O channels was monitored with a hardware monitor. The accounting package, LOGGER, collected the direct time for each job and the total number of block counts transferred by each job. In this section methods for calculating the resource utilization from the accounting data are described. The calculated values of the resource utilization are then compared with those measured by the hardware monitor.

PROCESSOR

The direct time (d_i) of every job in the synthetic workload is determined from the LOGGER data. Let the elapsed time for the synthetic workload be T and N be the total number of jobs in the workload. (N = 87 in our study.) The processor utilization $\mho_1$ in the normal state is given

$$\mho_1 = \frac{1}{T} \sum_{i=1}^{N} d_i \tag{A1}$$

The processor utilizations for the seven runs were calculated using the equation (A1). Table VIII presents these values and the corresponding values measured by the hardware monitor are also presented in the table for the purposes of comparison. The two sets of values agree fairly well. The LOGGER itself consumes some CPU time but it does not measure itself. The hardware monitor on the other hand, measures the LOGGER activity. The time for interrupt processing is usually charged to the interrupted job if no job switching

Table VIII

Comparison of the Processor Utilization Values

Experiment Number	Processor Utilization (%)	
	Accounting Data	Hardware Monitor
1	26.0	—
2	59.6	62.0
3	67.2	64.1
4	56.2	60.2
5	34.5	34.5
6	45.8	48.2
7	45.9	50.9
8	57.3	61.3

takes place. The LOGGER collects the data whenever the processor is in the normal state and does not collect the data when the system is in the master state (i.e., supervisory state). But the hardware monitor does collect the data for both the states. These considerations should be borne in mind when comparing the results in Table VIII.

I/O CHANNEL

The LOGGER records the total number of block counts to each channel. In the channel-device architecture, there is a primary channel (channel 2) and a secondary channel (channel 10) to achieve simultaneity. This results in the transfer of the block by channel 2. Whenever it is busy channel 10 takes over the transfer. The LOGGER does not distinguish between the number of block counts transferred to the primary and the secondary channel, but measures the total block count for the primary and the secondary combination. The hardware monitor, on the other hand, distinguishes between the primary and the secondary channel and measures the utilization of the two channels separately.

The devices used in the B3500 system are head-per-track disks and the data transfer takes place in three phases. During the first phase the track address is analyzed and the corresponding read/write head is connected to the channel. During the second phase the read/write head waits for the beginning of the track to rotate. The second phase is referred to as the latency. During the third phase the data transfer takes place. It should be pointed out that the channel and the device are busy during all the three phases. The seek is absent in the transfer process since no arm movement is involved.

The time per block count, t, can be expressed as

$$t = (\text{ave. Latency}) + (\text{Transfer Time}) + (\text{Overhead}) \qquad \text{(A2)}$$

where the average latency is the time for half a revolution of the disk, the transfer time is a function of the block size and the rate of transfer and the overhead includes the time for switching from track to track. The hardware characteristics of the disk-channel unit are given below.

Type	B9372-9
Rotation Speed	1300 RPM
Max. Latency	46 milliseconds
Ave. Latency	23 milliseconds
Rate of Transfer	377 kilobytes/second
Overhead	1.8 milliseconds

The block size for all the files in the test workload was 50 bytes. Based on these values the average time per block count is given by

$$t = 23.0 + \frac{50}{377} + 1.8 \simeq 23.0 + 0.13 + 1.8 \simeq 25 \text{ milliseconds} \qquad \text{(A3)}$$

The channel utilization can be calculated from the following expression

$$\mho_2 = \frac{(t)\ (B)}{T} \qquad \text{(A4)}$$

where

$\mho_2$ - channel utilization

t - time per block count = 0.025 seconds

B - total block count

T - elapsed time for the test workload

REFERENCES

1. ADPE Performance Management System, AFM 171-400, Volume III, 1 December 1972.

2. Burroughs B 2500 and B 3500 Information Processing Systems Assembler Reference Manual, PCN 1034949, November 20, 1970.

3. J. Esposito, "Statistical Analysis to Determine Digital Computer Workload Characteristics," ESD-TR-74-175, June 1974.

4. K. Sreenivasan and A. J. Kleinman, "Construction and Applications of Representative Synthetic Workloads," ESD-TR-73-212, August 1973.